μA702 CIRCUIT DESIGN IDEAS

Submitted by Users In Response To A Contest Run in the Electronic Trade Press

More than one hundred original circuit applications for the Fairchild μA702 integrated linear amplifier were submitted as entries in a contest held early in 1965. All were excellent, and space limitations alone prevent the publication of every circuit.

This brochure presents six ideas selected by the Fairchild Semiconductor applications department as representative of the many potential uses for the μA702. The first two circuits were judged top winners, and the authors each received a valuable stereo hi-fi system.

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TRANSFORMERLESS MODULATOR-DEMODULATOR

Submitted by C. J. Amato of Lear Siegler, Inc., Cleveland, Ohio

Frequently in the design of control or communication systems the need for a modulator or demodulator arises. In the past, matched diode bridges have been used in conjunction with transformers to perform this function. The approach has the disadvantage that the transformers operate over a relatively limited frequency range, usually require special designs, are bulky, and are expensive in small quantities.

The circuit described uses the μA702 as a full-wave modulator-demodulator that requires no transformers and uses only standard, readily-available parts. It will operate over a wide range of frequencies and is easily adapted to different applications.

Figure 1 is a schematic diagram of the circuit. Input switch Q_1 alternately switches the μA702 from an inverting amplifier configuration (with Q_{1A} on) to a noninverting connection (with Q_{1B} on). The inverting and noninverting gains are equal for $R_1 = R_2$, $R_3 = R_4$, and

$$R_6 = \frac{(R_1 + R_3)\, R_3\, R_5}{(R_1 + R_3)(R_3 + R_5) - R_3\, R_5} \qquad (1)$$

where the voltage gain is given by

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_5}{R_1 + R_3} \qquad (2)$$

For modulator operation, the input voltage (V_{in}) is a DC signal and the output is a square wave with magnitude proportional to V_{in} and either in phase or out of phase with the drive voltage (V_D), depending on the algebraic sign of V_{in}.

For demodulator operation, V_{in} is an AC voltage. With a sinusoidal input, the average value of V_{out} varies as the cosine of the phase difference between V_D and V_{in}. With a square wave input, the average value of V_{out} is a linear function of the phase difference of V_{in} and V_D.

In the circuit of Fig. 1, the switch transistors are operated in an inverted configuration to minimize offset. The push-pull drive signal can be readily obtained from an integrated circuit flip-flop. The circuit values give a gain of 10 and a 10-Mc bandwidth.

Additional advantages of using the μA702 are that a substantial gain can be provided, and the output impedance is quite low and constant throughout the switching cycle which simplifies output filtering.

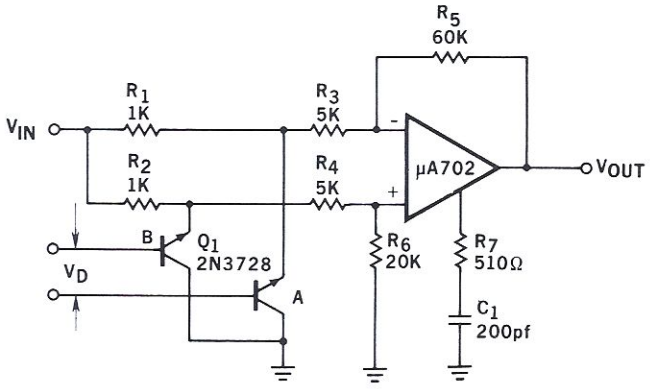

FIG. 1. Schematic of the Transformerless Modulator/Demodulator.

DELAY EQUALIZER

Submitted by J. Toffler of Hughes Aircraft Co., Fullerton, California

Facsimile, high-speed telegraphy, and data transmission are extremely vulnerable to delay distortion. For the compensation of this distortion in carrier systems and associated equipment, types of corrective networks are required that may be readily designed and individually adjusted to meet the conditions of a particular application. Generally designated as all-pass circuits, such networks have an amplitude characteristic that is essentially independent of frequency

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throughout the useful frequency range. A typical equalizer consists of a number of all-pass sections in tandem, each of which inserts a controlled amount of delay at selected frequencies.

A delay equalizer section using the μA702 DC amplifier is shown in Fig. 2. Its operation can be understood by writing the transfer function for the general configuration shown in Fig. 3:

$$\frac{V_{out}}{V_{in}} = \frac{(Z_1 + Z_4)\,Z_3 - (Z_2 + Z_3)\,Z_4}{(Z_1 + Z_4)(Z_2 + Z_3) - Z_4(Z_2 + Z_3)} \qquad (3)$$

For $Z_1 = Z_4$, $Z_2 = jX$ and $Z_3 = R$, Eq. (3) becomes

$$\frac{V_{out}}{V_{in}} = \frac{R - jX}{R + jX} \qquad (4)$$

which is the desired characteristic of an all-pass network.

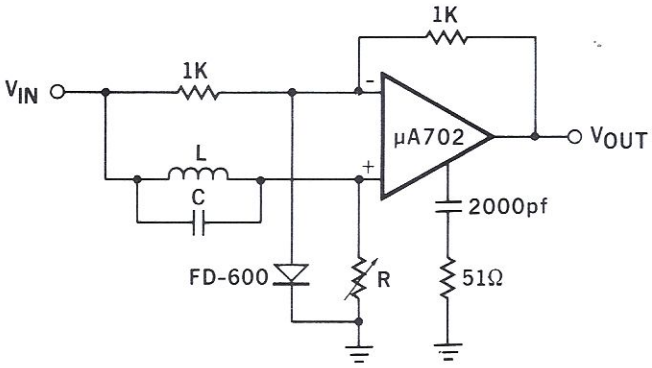


FIG. 2. Delay Equalizer Section Using the μA702.

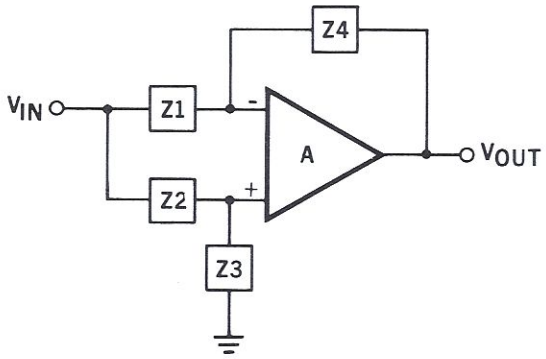


FIG. 3. General Configuration of a Delay Equalizer Section.

The advantages of the circuit become evident by comparing it with a conventional delay equalizer shown in Fig. 4. The conventional circuit requires an audio transformer and a large tantalum capacitor to operate properly at low frequencies. However, the differential input of the μA702 eliminates the need for a transformer (or a more complicated bridged section) while the low offset of the amplifier allows a large number of amplifiers to be directly coupled. In addition, the high open-loop gain gives a large amount of negative feedback and permits the desired transfer function to be approached more closely. These advantages are particularly significant when one considers that many applications require eight or more sections in tandem.

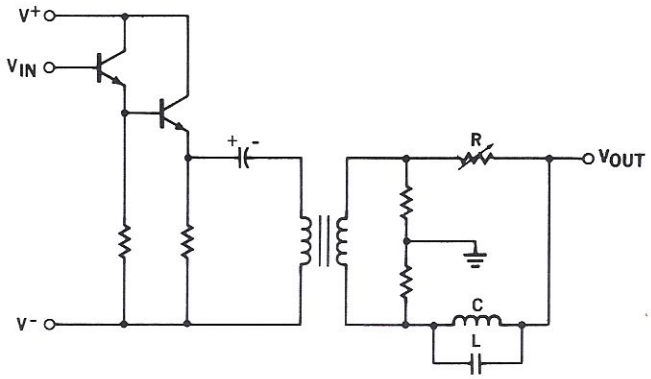


FIG. 4. Conventional Delay Equalizer Section.

ZERO-CROSSING DETECTOR

Submitted by Louis A. Watts of Emerson Electric Co.,
Santa Barbara, California

Often in the processing of electrical analog data, a power spectrum analysis of some particular signal waveform must be performed. This procedure requires that the frequency content of the signal waveform of interest, within a specified passband, be extracted from the broadband signal and noise. A zero-crossing detector using the μA702 operational amplifier provides a simple and effective means of performing such an operation.

A zero-crossing detector is a device which changes state each time the analog input signal passes through zero (or through its average reference level). The input signal is thus converted into a train of frequency dependent pulse widths. The resultant zero-crossing intervals then may be examined for frequency content.

This "infinite" clipping of the signal virtually eliminates distortion caused by amplitude fluctuations, circuit variations, and noise, and permits simplification of further data processing through the use of digital techniques. These features are especially valuable for information processing systems where signal storage and correlation processes are to be utilized, such as in digital beamformers and correlators.

The commonly used Schmitt trigger and multistage limiter-clipping circuits can exhibit large errors in zero-crossing information. The Schmitt trigger introduces distortion due to its large "on-off" hysteresis characteristic. The circuit does not change state when the input signal passes through zero, but at different levels for positive-going or negative-going signals.

Distortion in multistage limiters is caused by a shift in the average reference level after each successive stage of limiting. The shift in average level arises because the signal cannot be fully clipped in one operation. Large peaks (which may be of one polarity only) are clipped by the first stages of the limiter, thus altering the waveform to produce a different average level. The following limiter stage then clips the resultant signal about the new average level, which can completely change the character of the original signal.

The large voltage gain and dynamic range of the μA702 permit full clipping of a signal by a single stage of processing. The circuit shown in Fig. 5 exhibits a nearly ideal transfer characteristic for a zero-crossing detector.

The amplifier has full open-loop gain (about 70 db) when the output is less than the forward voltage limits of the diode network, and it has very little gain outside this range. Thus, an extremely wide dynamic range of input signals, including small voltage excursions on the order of ±500 microvolts, will completely drive the amplifier to the maximum output of ±1.5 volts. A random analog waveform fed into the input of the circuit thus will be uniformly clipped with negligible hysteresis or loss of average reference level.

A useful variation of the basic circuit is obtained by replacing R_1 in Fig. 5 by a capacitor. The output signal then changes state each time the input signal passes through an amplitude peak rather than through zero. Since the signal rate of change is zero at an amplitude peak, this peak-detector circuit functions as a zero-crossing detector for the first derivative of the input signal.

The use of both zero-crossing detectors and peak detectors results in simple, accurate data processing systems. For example, a position pick-off sensor, monitored by both circuits, would provide precise information regarding the time at which the system being measured passed through its rest position ($x = 0$) and when its velocity reached zero ($\frac{dx}{dt} = 0$).

These signals may be used as final output information, or may serve as timing or gating signals to initiate synchronous sampling of other instantaneous functions. The simplicity, reliability, and extremely small size of the μA 702 permit many such circuits to perform complex data processing in any easy and convenient manner.

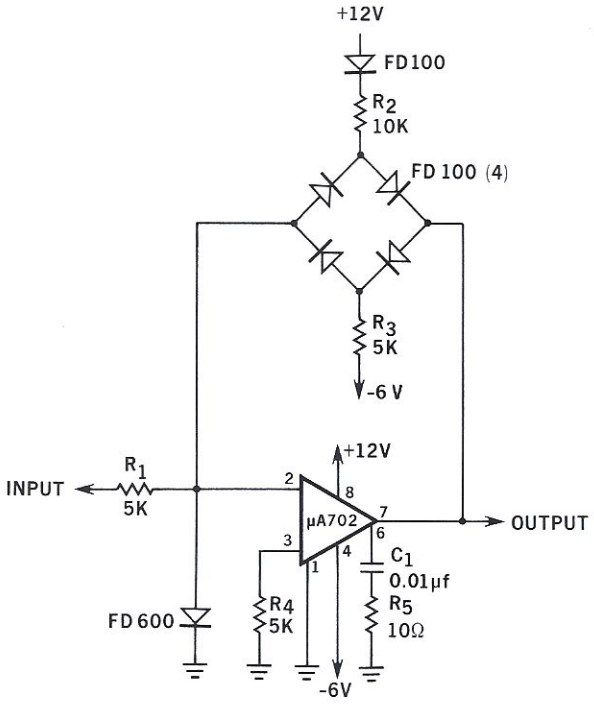


FIG. 5. Zero-Crossing Detector.

NUCLEAR REACTOR BISTABLE TRIP

Submitted by Kenneth A. Zimmerman of General Atomic, San Diego, California

Bistable trips in nuclear reactor safety systems are used to sense dangerous levels of neutron flux, temperature, pressure, etc. The function of these circuits is to sound an alarm and send a logic signal to the automatic safety system when a given output level from the monitoring transducer is exceeded.

An accurate and reliable bistable trip using a μA 702 operational amplifier is shown in Fig. 6. The output of the monitoring system is applied to the noninverting input through R_1. Since the voltage range of the sensor (0 to +10 volts) is outside the input voltage limits of the μA 702, the LEVEL SET potentiometer is returned to −12 volts to shift the level of the input signal to zero. When the input signal rises a few millivolts above the threshold voltage determined by the LEVEL SET control, the μA 702 will switch on, operating the relay driver and the alarm system. The diodes on the input protect the amplifier from damage due to excessive input voltages.

Adjustable hysteresis of the triggering level is provided by positive feedback through R_3 and R_4. This improves noise immunity and also serves to hold the amplifier on, once the triggering level has been exceeded. The amount of hysteresis is proportional to the output voltage swing and the positive feedback resistors. The output swing is clipped at 0.7 volt in the positive direction by the emitter-base junction of the driver transistor, and at −5.3 volts by the amplifier. With the resistor values shown, the hysteresis can be set anywhere between 10 mV and 100 mV.

The excellent temperature stability of the μA 702 provides a triggering repeatability nearly an order of magnitude better than that of more expensive circuits constructed with discrete components. The great reduction in physical size is also of considerable importance, since a typical nuclear system often employs 50 or more of the trip type circuits.

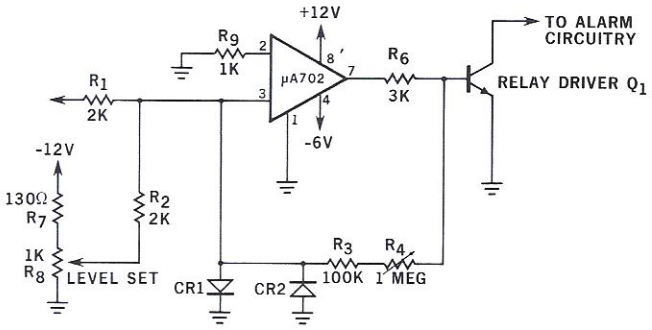


FIG. 6. Nuclear Reactor Bistable Trip.

MAKING A NYQUIST PLOT UNDER CLOSED-LOOP CONDITIONS

Submitted by Robert W. Allington of Ampex Corporation, Redwood City, California

In any closed-loop feedback system, it is desirable to measure the open-loop response. There are certain classes of closed-loop systems, however, which cannot be operated under open-loop conditions; therefore, the response must be measured while the loop is closed.

A Nyquist plot can be made by using the technique shown in Fig. 7. A disturbance, V_0, is added in the feedback path such that $V_0 + V_2 = V_1$, where V_2 is the amplifier output voltage and V_1 is the input voltage. Normalizing with respect to

$$V_1, \quad \frac{V_0}{V_1} + \frac{V_2}{V_1} = 1, \tag{5}$$

reveals that the second term is the open-loop gain of the system and the first term is the return difference. Since these two quantities are vectors, they may be used to plot the open-loop gain and phase of the system.

The main disadvantage of this procedure is the difficulty in inserting V_0 into the feedback loop. By using a pair of μA 702 operational amplifiers as shown in Fig. 8, the measurement can be readily made while still having one side of V_0 grounded. Amplifier U_1 operates as a unity-gain summing amplifier, and U_2 functions as an inverter. The circuit is compact and reliable and permits utilization of a measurement technique heretofore difficult to implement.

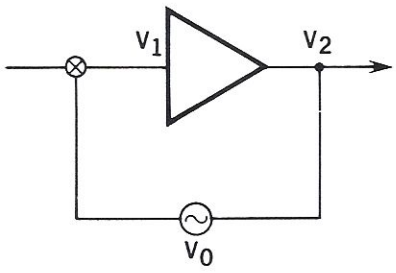


FIG. 7. Diagram Showing Insertion of Disturbance into Closed-Servo Loop.

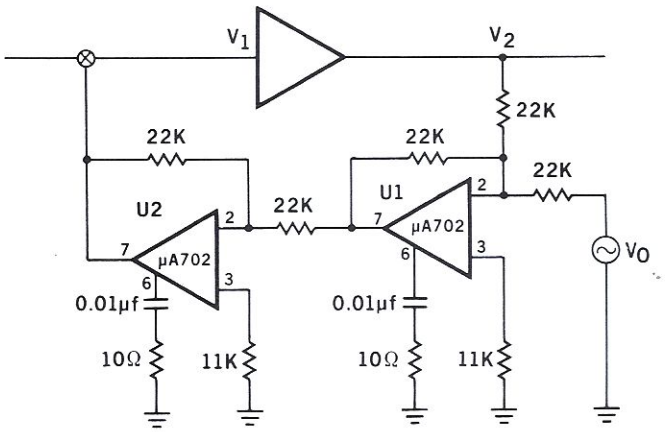


FIG. 8. Circuit for Introducing Disturbance from Single-Ended Source.

P.P.I. SWEEP GENERATOR

Submitted by Donald E. Lancaster of Goodyear Aerospace, Phoenix, Arizona

Two μA 702 operational amplifiers may be used to generate the waveforms required for a radial plan position indicator display. High linearity, uniform bilateral integration, rapid reset time, and an output that directly powers a deflection driver are some of the advantages obtained. In addition, the entire circuit is easily encapsulated in a small package instead of the several circuit boards required using conventional components.

The amplifiers in Fig. 9 are connected as two independent integrators, which are diode-clamped to zero until a range gate pulse arrives and allows the sweep waveform to begin. The input to each integrator is derived from the antenna or servo position as the sine and cosine output of a synchro resolver. The value of the sine or cosine of the input determines the rate at which the integrators reach the end of the range gate; the polarity of the input determines whether the integrators sweep positive or negative, thus giving four quadrant integration.

The amplifier outputs appear on the display as a series of radial sweeps. The time constants shown in Fig. 9 give several thousand radial sweeps for an antenna circular rate of about 40 rpm. The display is unblanked only during the sweep times.

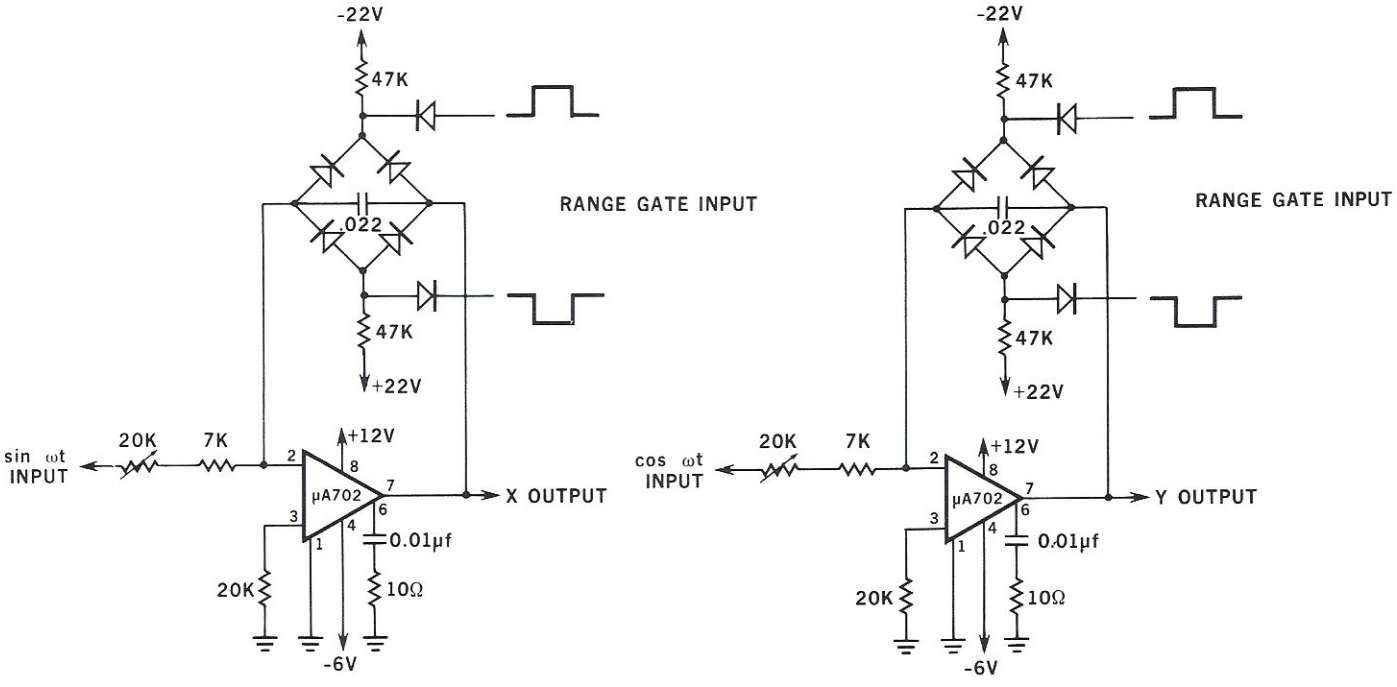


FIG. 9. P.P.I. Sweep Generator.

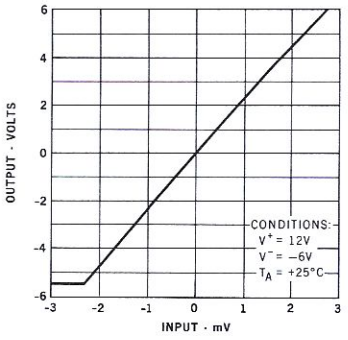
ELECTRICAL CHARACTERISTICS (25°C Free Air Temperature unless otherwise noted)

PARAMETER	CONDITIONS	$V^+ = 12V$ $V^- = -6V$			$V^+ = 6V$ $V^- = -3V$			Units
		Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage (ΔV_{in})	$R_S \leq 2K$	-	2	5	-	2	5	mV
Input Offset Current (ΔI_{in})		-	0.7	2	-	0.5	2	μA
Input Impedance (R_{in})		8	25	-	12	40	-	KΩ
Input Bias Current (I_{in})		-	4	10	-	2.5	7	μA
Input Common Mode Range		-4.0	-	+.5	-2.0	-	+.5	V
Common Mode Rejection Ratio (CM_{RR})	$f \leq 1$ Kc	70	80	-	70	80	-	db
Open Loop Voltage Gain (A_{vo})		1400	2600	-	380	700	-	
Open Loop Bandwidth (B_o)		0.55	0.8	-	0.55	0.8	-	Mc
Output Impedance (R_o)		-	200	500	-	300	700	Ω
Output Voltage Swing	$R_L \geq 100$ K	±5.0	±5.3	-	±2.5	±2.7	-	V
Average Temperature Coefficient of Input Offset Voltage	$25°C \leq T_A \leq 125°C$	-	5	-	-	5	-	μV/°C
	$-55°C \leq T_A < 25°C$	-	10	-	-	10	-	μV/°C
Input Offset Voltage	$R_S \leq 2K$, $-55°C \leq +125°C$	-	-	6	-	-	6	mV
Input Offset Current	$-55°C \leq T_A \leq 125°C$	-	-	3	-	-	3	μA
Open Loop Voltage Gain	$-55°C \leq T_A \leq 125°C$	1000	-	-	-	-	-	
Input Bias Current	$T_A = -55°C$	-	-	20	-	-	14	μA
DC Supply Power		-	70	120	-	17	35	mW
Positive Supply Voltage Sensitivity		-	50	-	-	100	-	μV/V
Negative Supply Voltage Sensitivity		-	100	-	-	200	-	μV/V

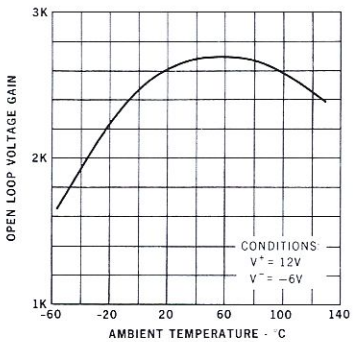
TYPICAL PERFORMANCE CURVES OF μA702A AMPLIFIER

ALL GRAPHS WITH $V^+ = 12V$, $V^- = -6V$, $T_A = +25°C$, UNLESS SPECIFIED

VOLTAGE TRANSFER CHARACTERISTIC

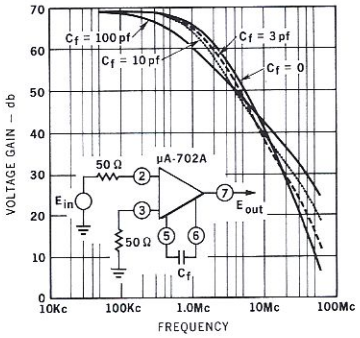


OPEN LOOP VOLTAGE GAIN AS A FUNCTION OF TEMPERATURE

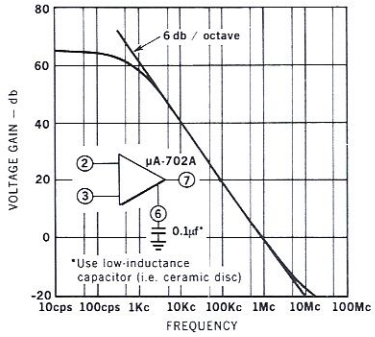


TYPICAL PERFORMANCE CURVES OF μA702A AMPLIFIER (Con'd)

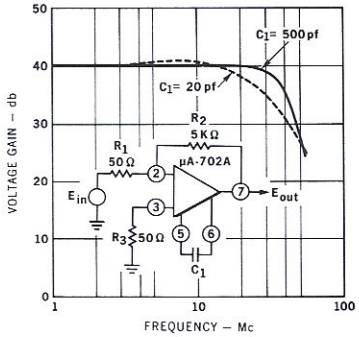
OPEN LOOP FREQUENCY RESPONSE FOR VARIOUS VALUES OF LEAD COMPENSATION CAPACITORS



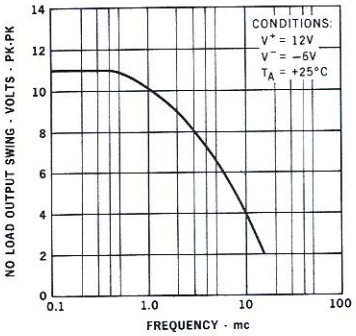
FREQUENCY RESPONSE OF μA702A WITH CONSERVATIVE FREQUENCY COMPENSATION NETWORK



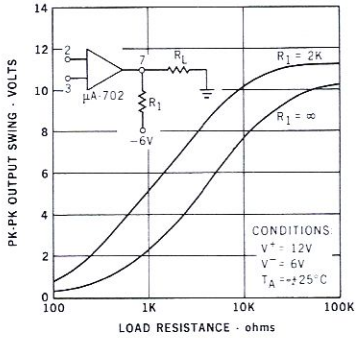
CLOSED LOOP FREQUENCY RESPONSE OF X100 AMPLIFIER



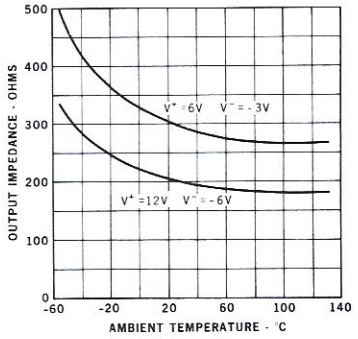
MAXIMUM OUTPUT VOLTAGE SWING AS A FUNCTION OF FREQUENCY



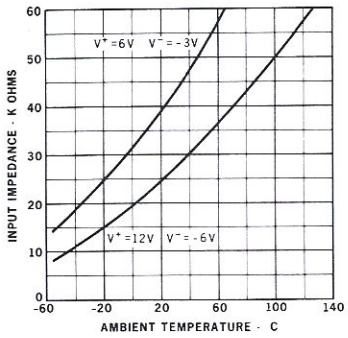
MAXIMUM OUTPUT SWING AS A FUNCTION OF LOAD RESISTANCE



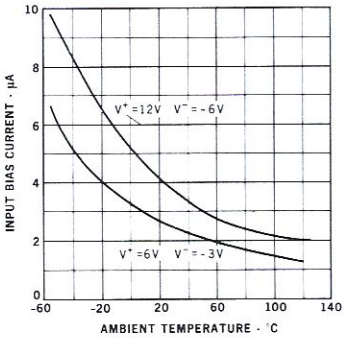
OPEN LOOP OUTPUT IMPEDANCE AS A FUNCTION OF TEMPERATURE



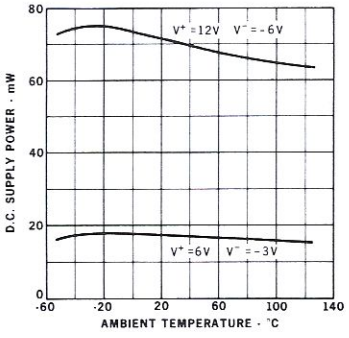
INPUT IMPEDANCE AS A FUNCTION OF TEMPERATURE



INPUT BIAS CURRENT AS A FUNCTION OF TEMPERATURE



DC SUPPLY POWER AS A FUNCTION OF TEMPERATURE



NOTE: Pin connections shown for TO-5 package.